The Durability Problem in Solar

Utility-Scale-Solar David Dumbelton: October 29, 2010 Guest Post

Solar modules exist in rough environments. So how do you avoid losses from degradation?

There is a reason why, to date, the vast majority of all PV installations have been based on crystalline wafer silicon. Work done over 40 years ago identified a system (cSi) that seemed to work quite well and that appeared reasonably durable. Subsequent experience demonstrated that, if the proper materials are chosen and combined with good workmanship, the resulting PV modules can be exposed to most outdoor environments for 20+ years and still produce over 80% of their original rated output.

Crystalline modules have been found to resist degradation from such normal weather factors as high heat, high humidity, high moisture, freeze-thaw cycles, normal hail occurrences, sand storms, snow load, and of greatest importance, daily exposure to high solar irradiance.

Concurrent with our increasing understanding of the durability of crystalline modules has been development of a number of other systems based upon different semiconductors and different combinations of materials. The new systems, whether CIGS, CIS, GaAs, aSi, CdTe, or other multi-junction combinations, each offer some economic or performance differentiation from the original glass crystalline modules. However, each must also undergo the same outdoor environmental conditions and risks as the original known performer. Often, the longer-term environmental durability of these materials is still unknown until they are exposed for extended periods of time.

When putting together an industrial-scale PV project installation, there are myriad financial considerations, among them the essential PV equipment and installation costs, grant support issues, the cost of investment money, anticipated operations and maintenance costs, incentives, and more. These costs are usually discussed in terms of Levelized Cost of Energy (LCOE), defined as the total cost of a system over its lifetime, divided by the total expected energy output of the system over that lifetime. The most critical element of all is the denominator of that equation, the anticipated return from the installation: the larger the return from the project, the lower the LCOE. Most models are based upon a Levelized Revenue Return (LRR) and LCOE over 20 years, but some are now being planned on the basis of 25 and even 30 years of useful life.

A number of nice financial models have been assembled by Mark Bollinger of the Lawrence Berkeley National Laboratory (see ref.) that show the kinds of assumptions being made relative to the anticipated returns of PV assemblages. The typical project cost and rate of return are based upon a project lifetime of 20 years. The important variables that depend upon the long-term durability of the PV modules are:

- The performance degradation in percent per year.
- The annual O & M cost in $ per kWDC per year where kWDC = rated output
- The escalation in Operations & Maintenance cost in percent per year
- The residual value of the installation after project life completed.
- Most PV performance contracts are currently written to an expectation of not more than 10% decline in the output performance after 10 years and 20% after 20 years; that is, an estimated performance decline of approximately 1% per year, if it is assumed that there is a uniform gradual decline in output and not a step change.

Let us suppose that an initial annual output of a set of modules is 1500 kWhrs/kWDC. In Bollinger's models, which assume a performance degradation of 0.5%/year, we would have a production of 1425 kWhrs/kWDC after ten years and 1350 kWhrs after 20 years. Assuming an average dollar value over these intervals of $0.20/kWh, the output of 1 kW of rated capacity at year 1 would be $300, at year 10 would be $285, and at year 20 would be $270.

Total return for the twenty-year period on this investment in 1,000 rated watts of PV modules would hence be $5700. Remember, this is only an example. In many countries, feed-in tariffs enhance this return to well over double this price per kilowatt-hour.

Suppose now that instead of a decline of 0.5% per year, we experience a more significant decline, beyond even the promised level of 1%/year, to, let us say, 2.5% per year. Let us further assume that this level of deterioration does not begin until after year 5, as most systems have been tested by HALT methods that will identify earlier sensitivities to environmental degradation.

Now the loss in output will amount to 40% in year 20, reducing our return to $180, and our total gain for the twenty-year period to about $5025, or 12% less return over the course of the project. Importantly, it also reduces the residual value of the installation going forward after the 20-year assumed life of the project.

This simple example demonstrates how critical the durability of the basic modules is to the financial logic of these projects. In this case, the modules simply lose more of their output capability than originally anticipated. But what if they begin to fail after seven or ten years, and must be replaced?

Although a normal budget for such projects includes an O & M cost and escalation as part of the plan and anticipates replacement of some inverters and perhaps a small number of modules, failure of a significant number of modules can throw an entire plan into chaos. Hence, it is imperative to obtain some kind of service life prediction (SLP) for the modules that we incorporate into such projects.

Such SLP information cannot be gained from certifications or material guarantees. It can only be obtained via one of two means: by field testing for the requisite period equal to the project length (a method that is obviously not suited to new products and technical improvements) or by evaluating the basic PV structure (module) in a synthetic environment that accelerates the anticipated effects of the real outdoor environment into which the PVs will be introduced.

It is already known that different constructions of modules have different sensitivities to environmental factors. For example:

1. The TCO (Transparent Conductive Oxide) layer of SnO2:F in thin film (aSi) modules is susceptible to electrochemical corrosion.

2. CdTe modules have a similar susceptibility, as well as a susceptibility to interlayer adhesion degradation due to climatic cycling;

3. CIS and CIGS modules are moisture-sensitive, with both the TCO and the package itself sensitive to moisture ingress.

4. OPV can experience moisture-induced degradation, as well as oxygen-induced degradation and photolytic instability.

With such a range of sensitivities, the only way to plan an accelerated life test is to reproduce all of the environmental stress tests concurrently and apply them to any test module in the same way, that is, to adopt a 'black box' approach to environmental exposure. By applying the various stresses at the normal extremes that might be experienced in nature, and by reducing the cycle times from the one per day experienced in nature to something considerably more rapid, we can obtain acceleration of the natural weathering processes.

It is also imperative that the stresses that occur concurrently in nature are applied in the same way in an artificial accelerated test. Hence, temperature and humidity need to be applied in the same manner as they occur in diurnal cycles, and solar energy must be supplied as part of the environment. PV modules should also be tested as they are in the real world, that is, under load. Testing them either in open or short circuit modes will create unrealistic results.

Methods have been developed to control heat, light and moisture in realistic environments to expose PV modules to true weather analogs in accelerated formats of cyclic changes (see ref). This series of concurrent exposures reveals whatever tendency the system that is being exposed has toward reduced output, as well as the onset of catastrophic modes of failure that might occur later in the normal life of the product. Although no absolute SLP can be arrived at from this approach, experience in weathering testing and an understanding of the systems being tested can result in a high degree of confidence in the ability of given systems to survive ten, twenty or even more years of outdoor exposure while still performing their assigned function.

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